



RESEARCH MEMORANDUM

EFFECTIVENESS OF A TURBOJET TUBULAR COMBUSTOR IN
SCREENING THE TURBINE FROM FOREIGN OBJECTS

By Patrick T. Chiarito

Lewis Flight Propulsion Laboratory
Cleveland, Ohio

NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS
WASHINGTON

July 18, 1955
Declassified January 20, 1958

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUM

EFFECTIVENESS OF A TURBOJET TUBULAR COMBUSTOR IN
SCREENING THE TURBINE FROM FOREIGN OBJECTS

By Patrick T. Chiarito

SUMMARY

The effectiveness of a tubular combustor in screening the turbine from foreign objects was measured with air flow corresponding to that at static sea-level rated operation. The objects used in the tests simulated those that might originate ahead of the combustor either outside or inside the engine. The benefits of several simple changes in a production combustor were evaluated in terms of decreased penetration of the objects through the combustor.

On the average, the effectiveness of the production combustor was only 36 percent for the foreign objects introduced in these tests; that is, 64 percent of the objects penetrated the combustor. The screening effectiveness of this type combustor may be improved by moving the bellows housing aft and radially outward.

Wire screens mounted over the air-intake holes reduced the penetration of objects even smaller than the screen openings. An 8-mesh screen over the air-intake holes and a 14- by 18-mesh dome screen reduced the average penetration of all objects to 3 percent. A 14- by 18-mesh wrapper or sock prevented any penetration.

The maximum pressure loss due to the screens was about 1/2 percent of the total pressure at the combustor inlet.

INTRODUCTION

The prevalence of foreign-object damage in turbojet engines has been recognized for several years (refs. 1 and 2). Stones, metal fasteners, and other objects that often litter a runway are accidentally ingested by the engine, for example, during tandem take-off. During flight, birds, battle debris, and flak might enter the induction system.

Furthermore, fasteners accidentally left in the engine during overhaul and sheet-metal pieces torn loose during engine operation may also cause severe damage.

Despite considerable effort to reduce the severity of damage by foreign objects, service records show that a large number of engines are still subject to damage. Excessive maintenance costs and loss of operational time result. Unfortunately, the problem has not been solved by the use of air-inlet screens alone. Because there is much disagreement about the value of inlet screens, other remedies are considered.

When a foreign object is ingested by a turbojet engine, either the compressor or turbine, or both, may be affected. For engines with centrifugal-flow compressors, the damage is usually more severe in the turbine than in the compressor. On the other hand, the axial-flow compressor is almost always more severely damaged; but the turbine is often affected also. The most common types of turbine-blade damage are scratches and nicks caused by the impact of the foreign objects. These scratches cause stress concentrations that reduce both the fatigue life and the stress-rupture strength of the ductile alloys which are used for turbine blades (refs. 3 and 4).

There is an urgent need for better materials for turbine blades to operate at the higher temperatures which are being demanded to increase thrust. Among the required properties of these materials are corrosion resistance, high stress-rupture and fatigue strengths, and resistance to thermal shock (ref. 5). Cermets possess an excellent combination of these properties but are extremely brittle. Although experimental cobalt- and nickel-base alloys are not as brittle as cermets and have some of the other required properties, they also have less ductility than the alloys that are being used in production. In view of the possible hazardous effect of turbine-blade damage, it is desirable to screen the turbine from foreign objects. Even a minor scratch in a ductile alloy will reduce the strength in the notch-sensitive range. With the possibility of using less-ductile materials because of their better high-temperature properties and the trend toward multistage turbines, the need for screening the blades is even more important.

The purpose of this investigation was (1) to study the effectiveness of a standard tubular combustor in screening the turbine from foreign objects that originate forward of the combustor, and (2) to determine whether simple changes in the combustor will increase its screening effectiveness. The J47 combustor was chosen because its configuration is representative of those used in several production engines. Simulated foreign objects of known types were injected into

the air stream ahead of a single combustor. The air flow corresponded to that at static sea-level rated operation. The screening effectiveness of the combustor was measured in terms of the percentage of objects that did not go through to the turbine section.

APPARATUS

Simulated Combustor Assembly

The J47 combustion-chamber inner liner shown in figure 1 was mounted in an outer chamber, the cylindrical portion of which was simulated in Lucite. The bellows (at the downstream end of the shell) was omitted, but its housing was simulated in Lucite. The resulting combustor assembly is shown in figure 2. The steel rods compressed rubber O-rings between the ends of the Lucite cylinder and steel rings welded to the ends of the shell to effect an air-tight joint. The fuel nozzle was used only to support the liner; no fuel was used. The air adapter and the transition piece also simulated the engine installation.

Combustor Configurations Tested

The six configurations that were simulated for the tests are shown in figure 3 and described in the following paragraphs:

Configuration A (standard). - The production combustor was used to establish a standard for evaluating the simple changes.

Configuration B. - The bellows housing of the standard combustor (simulated by the inner Lucite cylinder) was moved $1\frac{1}{4}$ inches aft, because the incline was obviously guiding the larger objects through the last row of air-intake holes.

Configuration C. - An 8-mesh screen was mounted over all air-intake holes of the standard liner. These screens were made by spot welding 0.010-inch stainless steel wire to the Inconel liner. The annular opening at the dome was covered by 14- by 18-mesh bronze fly screen soldered around its outer edge to the liner and fitted to the fuel nozzle at its inner edge. The alternate position of the bellows housing ($1\frac{1}{4}$ in. aft) was retained.

Configuration D. - The air-intake holes and the dome of the standard liner were screened as in configuration C, but the bellows housing was returned to its standard position in order to evaluate only the effect of the screens.

Configuration E. - The standard liner was wrapped with 14- by 18-mesh screen wire cloth, which covered all air-intake holes and louvers. The wire strands were at a 45° angle to the axis of the chamber to facilitate pulling the cloth tight over the conical surface of the liner. The same mesh covered the dome opening.

Configuration F. - The same size screen wire cloth (14- by 18-mesh) was used to make a conical sock which was fastened to the inner wall of the outer combustor chamber (i.e., the Lucite cylinder) immediately ahead of the bellows housing and stretched forward to join the liner at the dome welds. The dome opening was again covered with 14-by 18-mesh screen.

Test Installation

The test facility is shown schematically in figure 4. Air was supplied at a pressure of 40 pounds per square inch gage and at room temperature and was exhausted to the atmosphere. The air-flow rate was manually controlled by butterfly valves and metered by a sharp-edged orifice, which was installed according to A.S.M.E. specifications. The inlet-air pressure was measured by two six-point total-pressure rakes and indicated by an absolute manometer. The inlet-air temperature was measured by a single-junction iron-constantan thermocouple and indicated by a self-balancing potentiometer. The total-pressure drop through the combustor was determined by a water differential manometer installed between probes at the locations shown in the sketch. Objects were injected upstream of the combustor. The objects that penetrated were collected downstream, except those that were blown out the exhaust stack.

Foreign Objects Used in Tests

The sizes of objects used included several that would pass through an air-inlet screen (USAF specifications permit louvered inlet screens with 1/4-in. spacing). The shapes of the objects simulated stones and fasteners that usually litter a runway and sheet-metal fragments that might be broken from guide vanes. Objects that might be accidentally left in the engine during overhaul were also simulated.

Specifically, the following objects were used:

Size	Shape	Material
3/32-In.-diam.	Ball	Alloy steel
3/16-In.-diam.	Ball	Alloy steel
5/16-In.-diam.	Ball	Alloy steel
0.040 By 1/4 by 1/4 in.	Sheet	Inconel
0.040 By 1/4 by 3/8 in.	Sheet	Inconel
0.040 By 1/2 by 1/2 in.	Sheet	Inconel
No. 8-32	Hexagonal nut	Mild steel
No. 8-32 by 1/2 in.	Round-head machine screw	Mild steel

PROCEDURE

The reference air velocity through the combustor (calculated from inlet-air density, air-flow rate, and a maximum combustor cross-sectional area of 0.505 sq ft) was adjusted to 115 feet per second. This velocity represents static sea-level rated operation of the J47. While this test condition was maintained, 50 objects of each size were injected singly into the air stream upstream of the combustor inlet. The paths of the objects were observed with the aid of mirrors above and below the combustor (fig. 4). Three tests were run for each of the first four configurations (making a total of 150 objects injected of each size); one test was run for each of the other two.

The objects that penetrated the combustor were not all retrieved. The number of objects that passed through was computed as the difference between the number injected and those that remained within the combustor. The effectiveness of the combustor as a screen for the turbine was defined as the percentage of objects that did not penetrate.

After the screening effectiveness of the standard combustor was determined, modifications were made and the benefits (in terms of increased screening effectiveness) were measured.

RESULTS AND DISCUSSION

The percentages of objects that penetrated the combustor are plotted in figure 5 for the first four configurations. There are no plots for the last two configurations because the average penetration was zero. The effectiveness of the combustor as a screen for the turbine is measured by the percentage of objects that did not penetrate.

The maximum total-pressure loss due to the screens was about 10 percent of the total-pressure loss in the standard combustor. This maximum loss was measured for the fine-mesh conical sock (configuration F). Because the standard combustor causes a total-pressure loss of about 5 percent, the maximum effect of the screens would be to increase the pressure loss by 1/2 percent. For the J47 engine, an increase in pressure loss of 1/2 percent would result in an increased thrust loss of even less than 1/2 percent.

Configuration A (Standard)

The average penetration in the standard combustor, as shown in figure 5(a), is 64 percent (i.e., average screening effectiveness is 36 percent). Individual values varied from 42 percent for the 3/16-inch-diameter ball to 94 percent for the 5/16-inch-diameter ball. In general, penetration depended upon the size and shape of the objects. These data show that the standard combustor cannot be relied upon to screen the turbine from foreign objects that originate within the engine, nor from those that penetrate the inlet screen and compressor.

In figure 6 is shown the disposition of objects that did not go through the standard liner after the air flow was shut off. Not shown are the few that were trapped in the dome.

It was impossible to follow the path of any of the 3/32-inch-diameter balls because of their small size and rapid movement. About half of the balls passed through the annular space between the liner and the outer chamber and were trapped in the bellows housing (see fig. 6). Those that penetrated were probably deflected into the last row of holes by the incline of the bellows housing.

Of the 3/16-inch-diameter balls that did not go through the liner, 6 percent were trapped in the dome, 10 percent in the bellows housing, and 42 percent were jammed between the liner and bellows housing (see fig. 6).

The 5/16-inch-diameter balls followed a rather direct path to the incline of the bellows housing and then through one of the holes in the last row. Only 2 percent were trapped in the dome and 4 percent were jammed between the liner and the housing.

The sheet-metal particles generally turned end over end in the air stream and were frequently caught temporarily in the louvers. Some traveled edgewise throughout the combustor. Again the incline helped these particles through the last row of air-intake holes. Some entered the louvers, and others probably went through the dome louvers.

The hexagonal nuts, the most active objects, retraced a circular path in the bottom of the outer chamber until they climbed the incline and went out a hole in the last row.

The machine screws bounced erratically and a few entered the air-intake holes near the middle of the liner. Most of the screws were assisted out the last row of holes by the incline; the others were jammed at the housing.

Configuration B

It was apparent that the incline was assisting the objects (especially the 5/16-in.-diam. balls) through the liner. However, moving the incline $1\frac{1}{4}$ inches downstream had little effect on the average penetration (fig. 5(b)), even though individual values decreased as much as 16 percent and increased as much as 26 percent. The most noticeable effect was the extreme delay in penetration by the 5/16-inch-diameter balls, the hexagonal nuts, and the machine screws. Some of these balls circled as many as 20 times before going through one of the holes in the last row. Many of the nuts and machine screws traced a figure-eight path several times before going through.

Because the clearance between the conical liner and cylindrical bellows housing was decreased by relocating the bellows housing, the larger objects no longer jammed in the annular space and eventually entered a hole in the last row. In general, the penetration of objects that were small enough to continue through to the bellows decreased.

On the other hand, if the annular clearance had been increased to slightly more than 5/16 inch, it is expected that even the larger objects would have been trapped within the bellows housing. In figure 7 is shown a proposed configuration which includes both the movement aft of the incline and the increase in radial clearance between the liner and the bellows housing. These changes would be expected to improve the effectiveness of the J47-type combustor in screening the turbine from the objects used in these tests.

Configuration C

Attempts to reduce penetrations by mounting screens over the holes and dome were quite effective. The average penetration was reduced to 3 percent after the 8-mesh screen was installed over the air-intake holes and the 14- by 18-mesh screen over the dome (with the bellows housing $1\frac{1}{4}$ in. aft)(fig. 5(c)). Although the 8-mesh screen was coarse

enough for the 3/32-inch-diameter balls to pass through, only 14 percent did so. The few sheet-metal particles that penetrated went through the cooling louvers.

In figure 8 is shown the jamming of 3/16-inch-diameter balls at the housing and the build-up of some 5/16-inch-diameter balls at the last row of holes during air flow. Some 3/16-inch-diameter balls passed through the annular space because the clearance was ample in some places. These balls were then trapped in the bellows housing. The activity of some of the other balls is indicated by the streaks in the bottom of the combustor. These screens were so effective and thus caused so much congestion in the combustor that the air flow had to be shut down and the steel balls removed. The test was completed after injection of sheet metal and fasteners; a similar build-up was then observed in five rows of holes along the bottom of the combustor.

Configuration D

Replacing the bellows housing in the standard position had a negligible effect on the average penetration (fig. 5(d)). The increase in penetration by the 3/32-inch-diameter balls from 14 to 22 percent (as compared with configuration C) was probably caused by the relocation of the bellows housing. More 3/32-inch-diameter balls were reflected by the incline and traveled a direct route out the last row of holes. As in the previous configuration, the few sheet-metal particles that penetrated the liner probably entered the louvers.

The grouping of sheet metal and fasteners around the holes during air flow is shown in figure 9. Also shown are some screws that jammed and the large accumulation of objects in the bellows housing.

Because these screens were so effective in retaining objects, it was desirable to measure the durability of such screens at normal engine operating temperatures. Six 8-mesh screens were made of each of three heat-resistant wire materials, the exact compositions of which were not known. The wires were spot-welded at all intersections. One screen of each type was mounted over holes at each end and at the middle of two liners, one of which was in an ignition chamber. After the J47 engine had been run for 45 hours at static sea-level conditions (95 percent at rated operation), the screens appeared to be in satisfactory condition (fig. 10). Although some spot-welded joints and short pieces of wire were broken, the benefit of the screen in shielding the turbine from foreign objects would have been substantially maintained. Additional studies of materials and fabrication methods should be made before such screens are used.

Configuration E

The 14- by 18-mesh screen wrapped around the standard liner and covering the dome (fig. 3) precluded penetration by even the 3/32-inch-diameter balls, so long as the screen remained intact. Accidental shifting of wires enlarged the openings in the screen at several locations and allowed one 3/32-inch-diameter ball to enter. This probably would not have happened if the wires had been welded at intersections and not merely woven. The dome screen was broken at two places and one sheet-metal particle, 1/4 by 3/8 inch, passed through.

This test indicates that a standard tubular combustor can be modified to greatly improve its effectiveness as a screen for the turbine. The choice of mesh must be a compromise based on the size of foreign object expected and pressure loss that will be tolerated.

Configuration F

The 14- by 18-mesh sock and dome screen (fig. 3) also permitted penetration of only one 3/32-inch-diameter ball (after the openings were enlarged by accidental shifting of wires). The several sharp nicks in the screen wires were probably caused by the sheet metal.

Compared with the wrapper, the sock seems to have no advantage in view of its susceptibility to damage, difficulty of fabrication, and slightly larger pressure loss.

SUMMARY OF RESULTS

This investigation of the J47 tubular combustor has shown that:

1. The production combustor is only 36 percent effective in screening the turbine from the objects used in these tests to simulate typical foreign objects. An average of 64 percent of the objects injected passed through the liner. Individual penetrations ranged from 42 to 94 percent and generally increased with size for each shape of object.

2. The incline of the bellows housing deflected objects through the last row of air-intake holes, especially those that were too large to jam between the liner and the bellows housing. The screening effectiveness of this type of combustor may be improved by moving the incline aft and increasing the annular clearance between the liner and bellows housing.

3. Wire screens mounted over the air-intake holes reduced the penetration of objects even smaller than the screen openings. An 8-mesh screen over the holes and a 14- by 18-mesh dome screen increased the screening effectiveness of the standard combustor to an average of 97 percent. The pressure loss due to the screens was less than 1/2 percent of the total pressure at the combustor inlet.

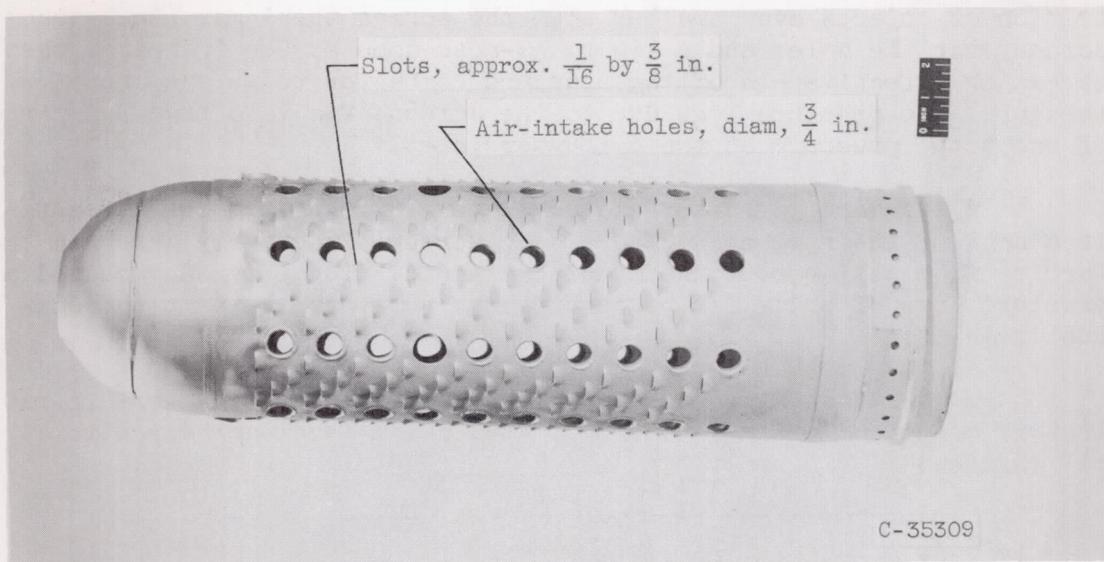
4. A standard combustor with a 14- by 18-mesh wire-cloth wrapper, or a sock of the same mesh, and a dome screen effectively screened the turbine from all objects used in these tests. These screens caused a pressure loss of about 1/2 percent of the total pressure at the combustor inlet.

5. Heat-resistant wire screens over air-intake holes were in satisfactory condition after 45 hours of static sea-level operation in a J47 engine.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, May 18, 1955

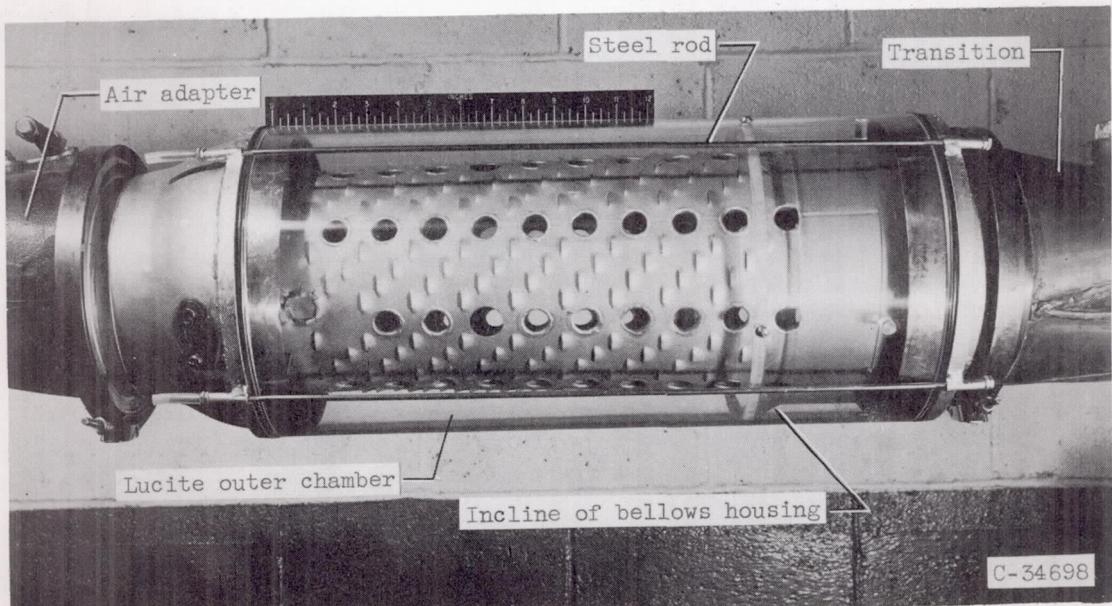
REFERENCES

1. Hazen, Ronald M.: Experience and Development of Turbojet Engines. Paper presented at meeting Inst. Aero. Sci., Cleveland (Ohio), Mar. 14, 1952.
2. Litton, R. S.: Inlet Protection for Aircraft Gas Turbine Engines. Preprint No. 297, SAE, 1954.
3. Brown, W. F., Jr., Jones, M. H., and Newman, D. P.: Influence of Sharp Notches on the Stress-Rupture Characteristics of Several Heat-Resisting Alloys. Symposium on Strength and Ductility of Metals at Elevated Temperatures, A.S.T.M., 1953, pp. 25-45; discussion, pp. 46-48.
4. Newman, D. P., Jones, M. H., and Brown, W. F., Jr.: Time-Temperature Dependence of the Notch Effect and Influence of Notch Depth in Stress Rupture Tests on a Cr-Mo-V Steel. Proc. A.S.T.M., vol. 53, 1953, pp. 677-692.
5. Ault, G. Mervin, and Deutsch, George C.: Applicability of Powder Metallurgy to Problems of High Temperature Materials. Jour. Metals, vol. 6, no. 11, Nov. 1954, pp. 1214-1226; discussion, pp. 1227-1230. (See also Trans. A.I.M.E., vol. 200, 1954, pp. 1214-1226; discussion, pp. 1227-1230.)



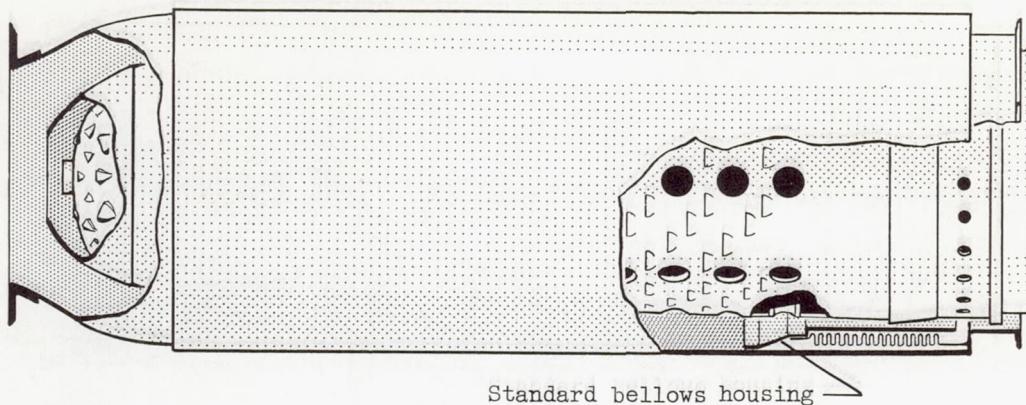
C-35309

Figure 1. - Inner liner for J47 combustion chamber.

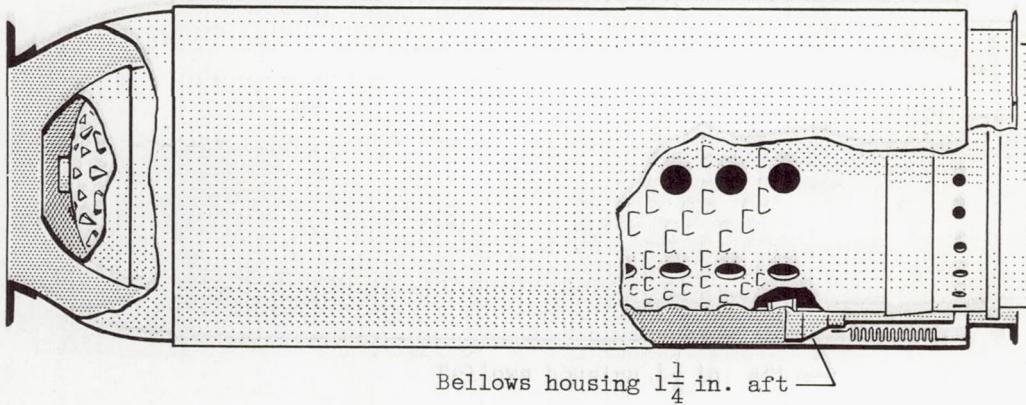


C-34698

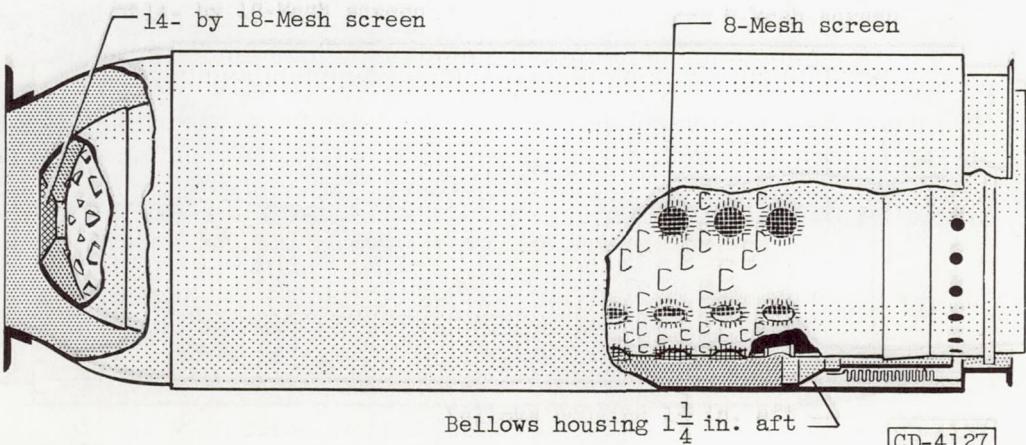
Figure 2. - Simulated combustor assembly used in tests.



(a) Configuration A (standard).



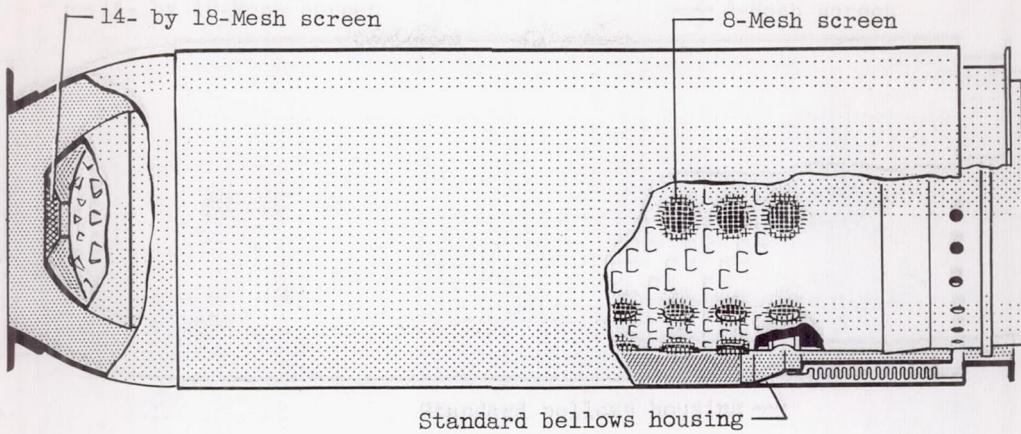
(b) Configuration B.



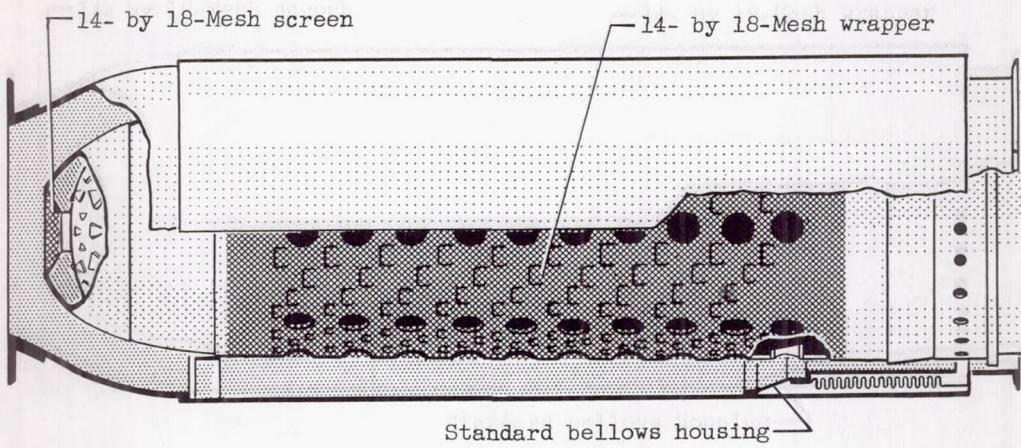
(c) Configuration C.

Figure 3. - Six combustor configurations simulated for tests.

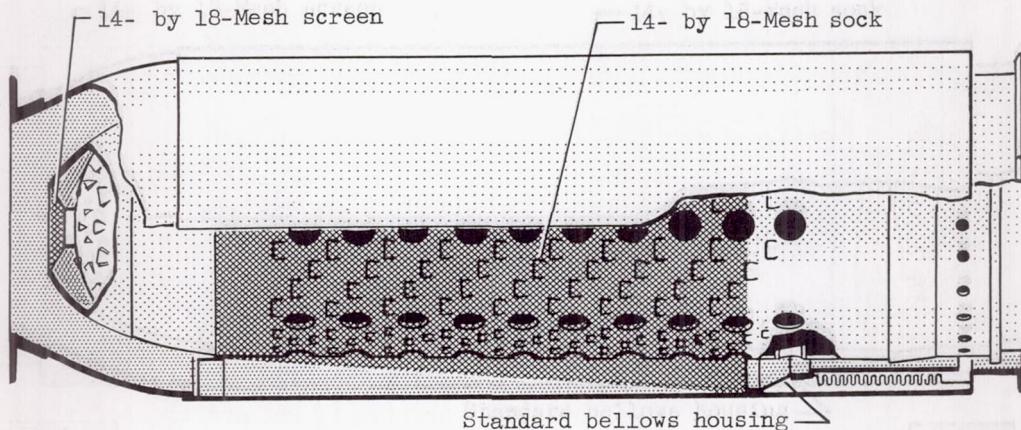
CD-4127



(d) Configuration D.



(e) Configuration E.



(f) Configuration F.

CD-4126

Figure 3. - Concluded. Six combustor configurations simulated for tests.

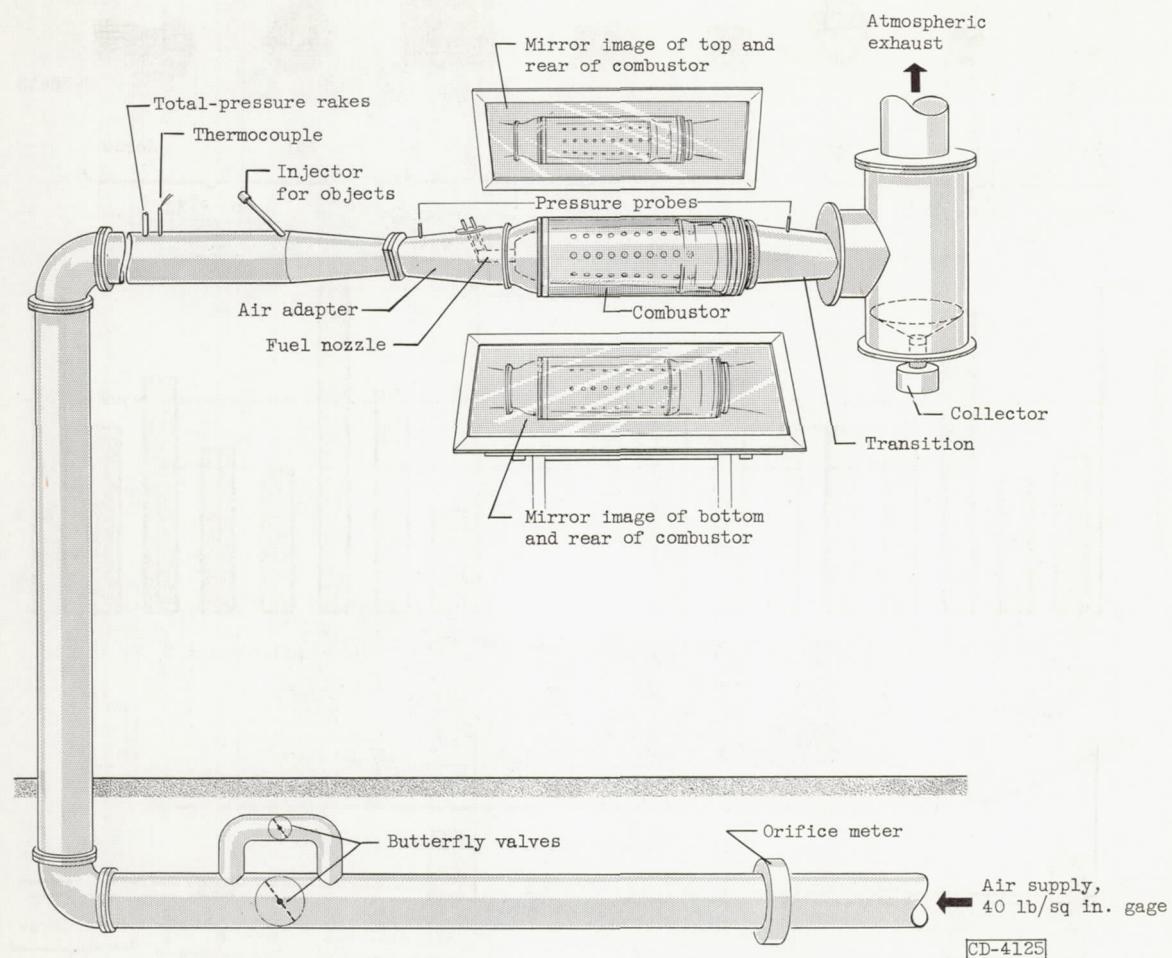
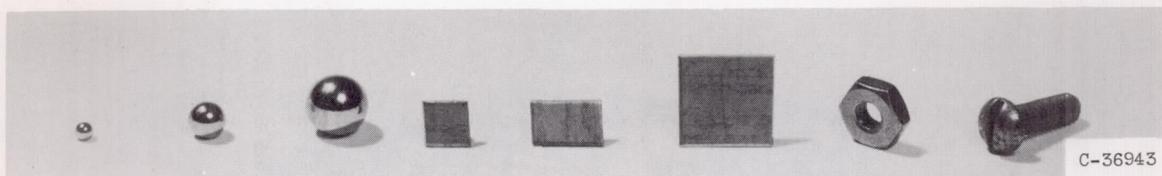
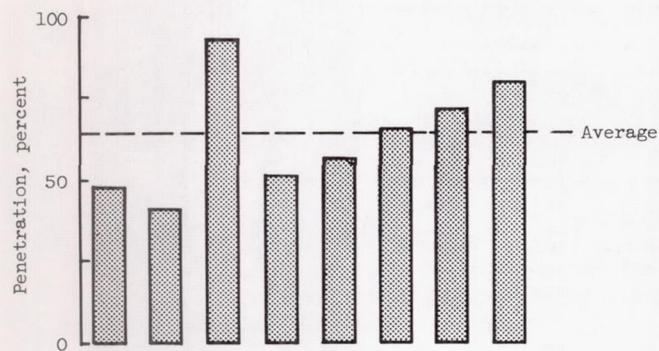


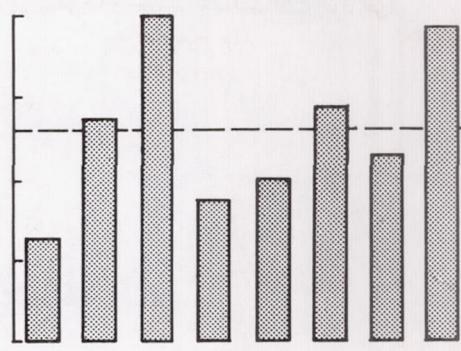
Figure 4. - Apparatus used to measure effectiveness of tubular combustor in screening turbine from foreign objects.



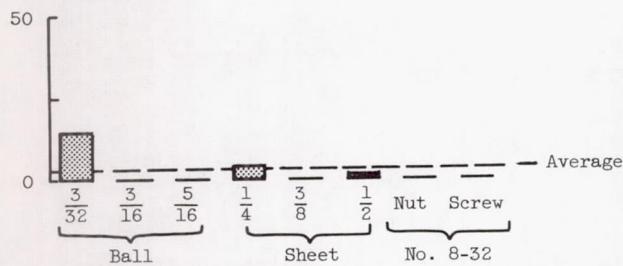
Foreign objects used in tests.



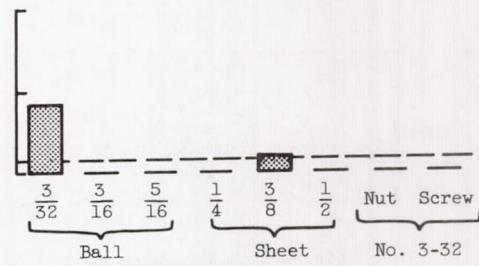
(a) Configuration A (standard).



(b) Configuration B.



(c) Configuration C.



(d) Configuration D.

Combustor configuration	Screens added to standard liner	Position of bellows housing	Average penetration, percent
A	---	Standard	64
B	---	1 $\frac{1}{4}$ In. aft	65
C	8-Mesh on holes; 14- by 18-mesh on dome	1 $\frac{1}{4}$ In. aft	3
D	8-Mesh on holes; 14- by 18-mesh on dome	Standard	3
E	14- by 18-Mesh wrapper	Standard	0
F	14- by 18-Mesh sock	Standard	0

Figure 5. - Penetration of combustor configurations by foreign objects.

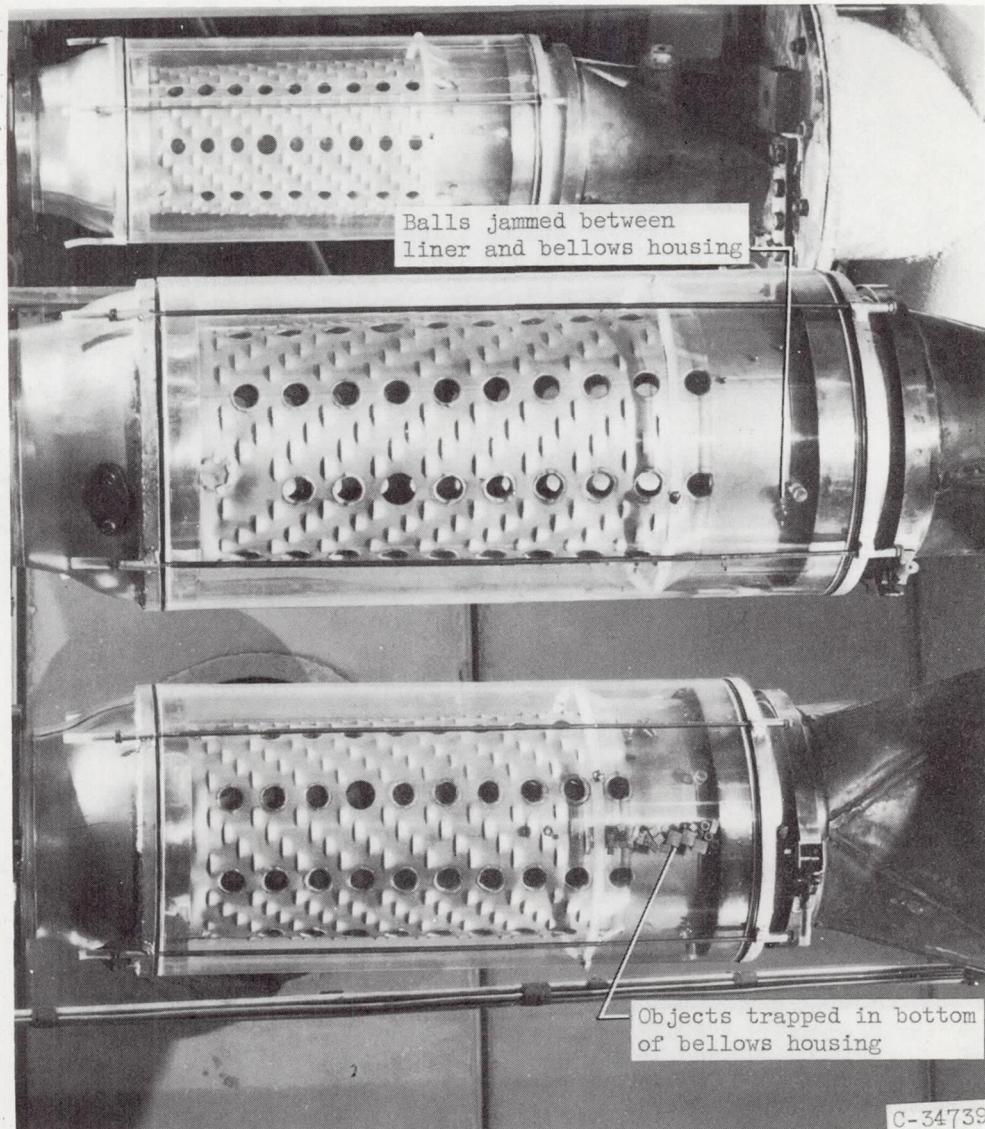
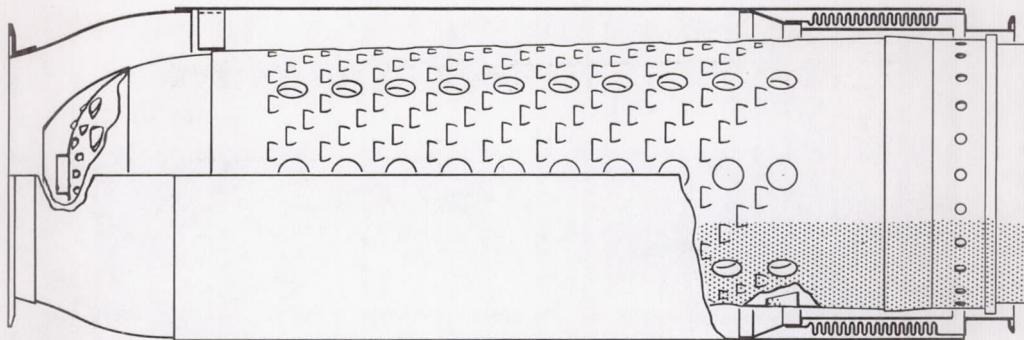
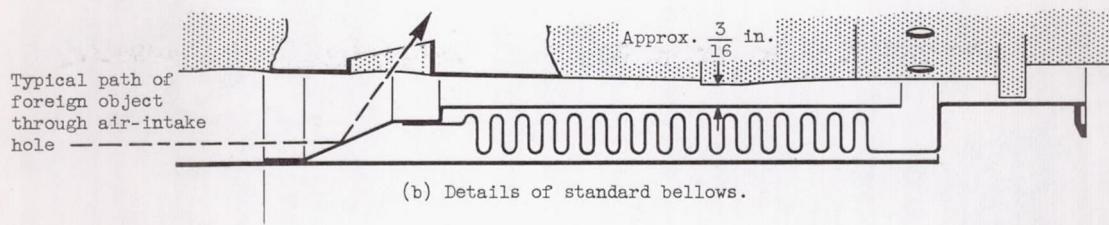


Figure 6. - Standard combustor (configuration A) showing disposition of objects after air flow was shut off. (Combustor is in middle; images of top and bottom appear in mirrors.)



(a) Production-combustor assembly.



(b) Details of standard bellows.

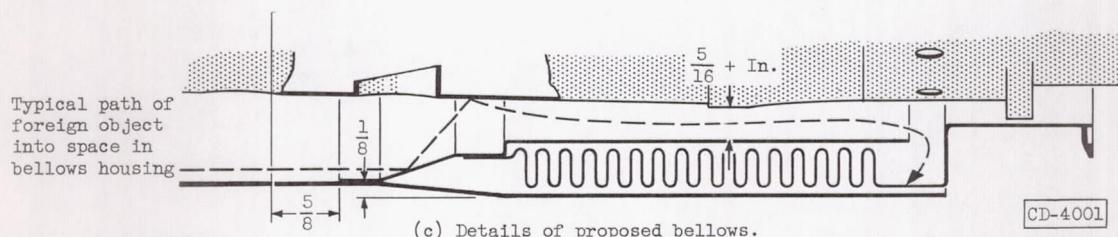


Figure 7. - Changes in location of J47 type bellows housing that would improve screening effectiveness of combustor.

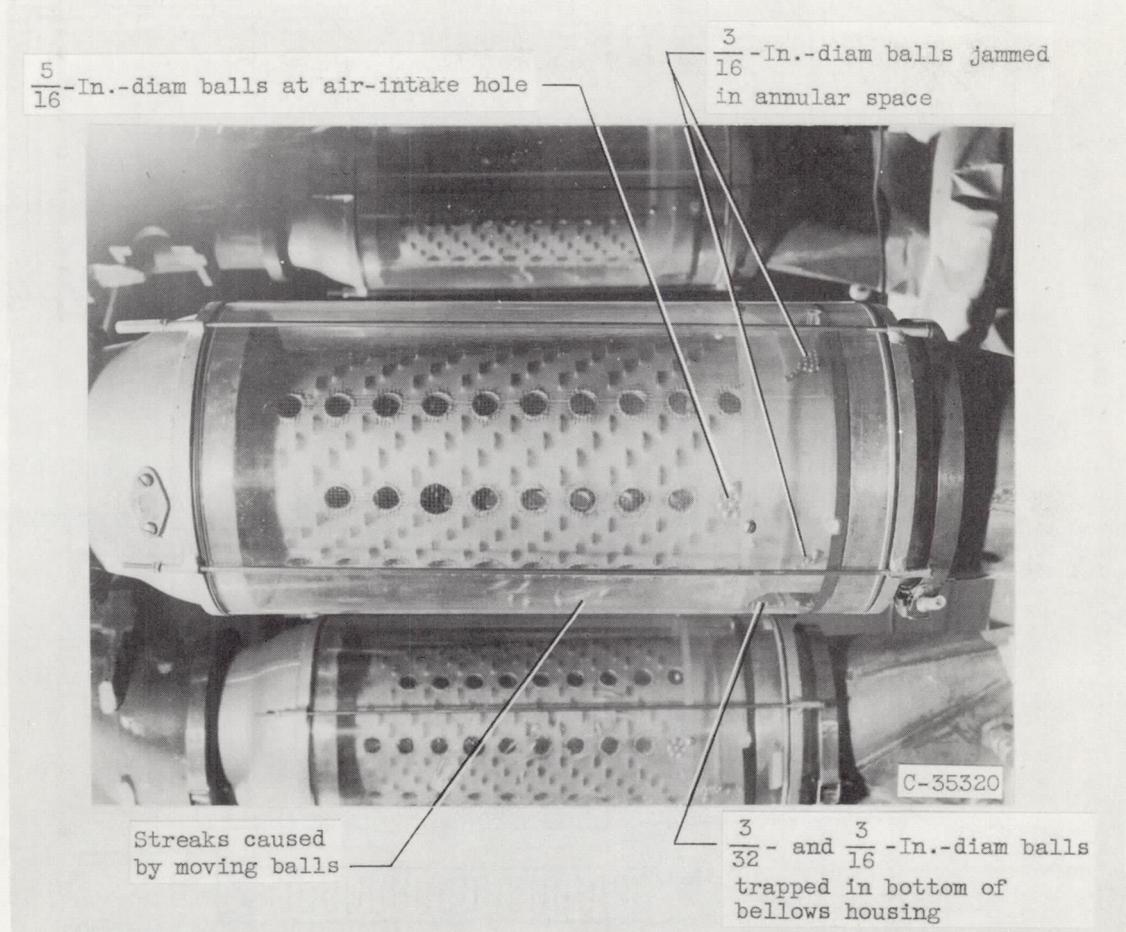


Figure 8. - Combustor with 8-mesh screen over air-intake holes and bellows housing moved $1\frac{1}{4}$ inches aft (configuration C) showing accumulation of some balls and activity of others during air flow.

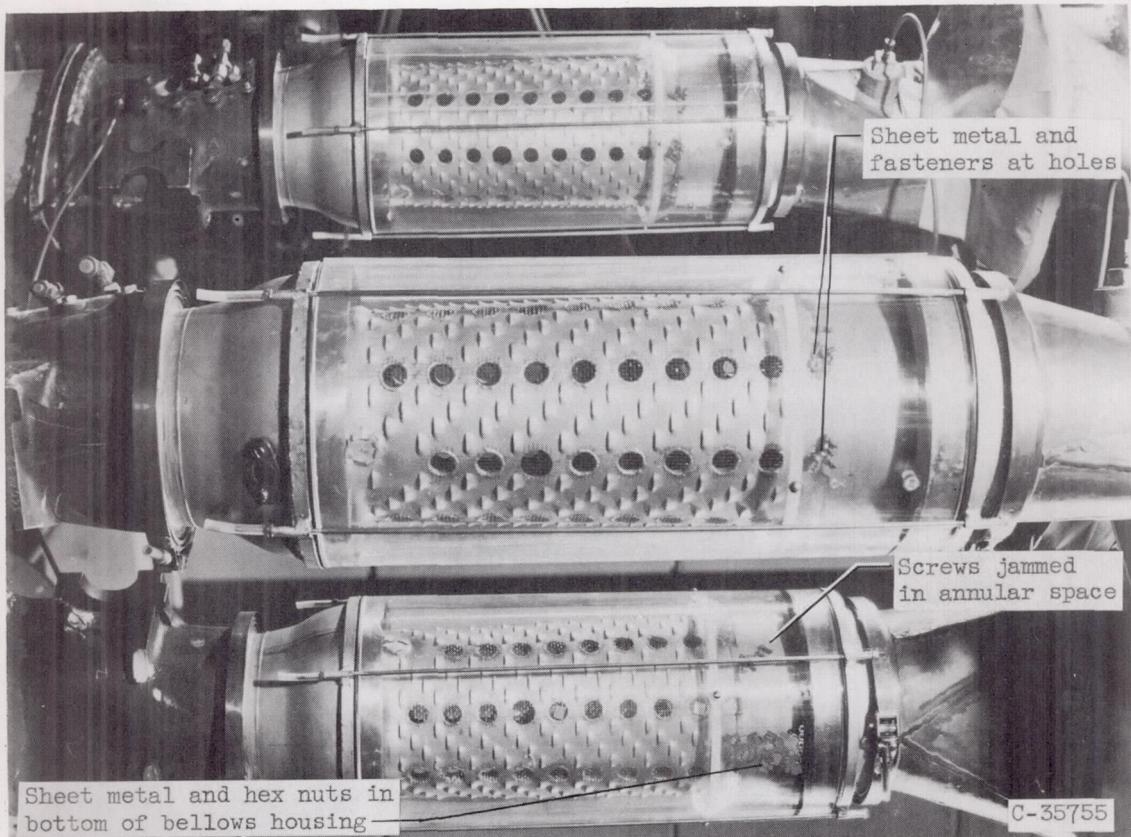


Figure 9. - Combustor with 8-mesh screen over air-intake holes and bellows housing in standard position (configuration D) showing accumulation of sheet metal and fasteners during air flow.

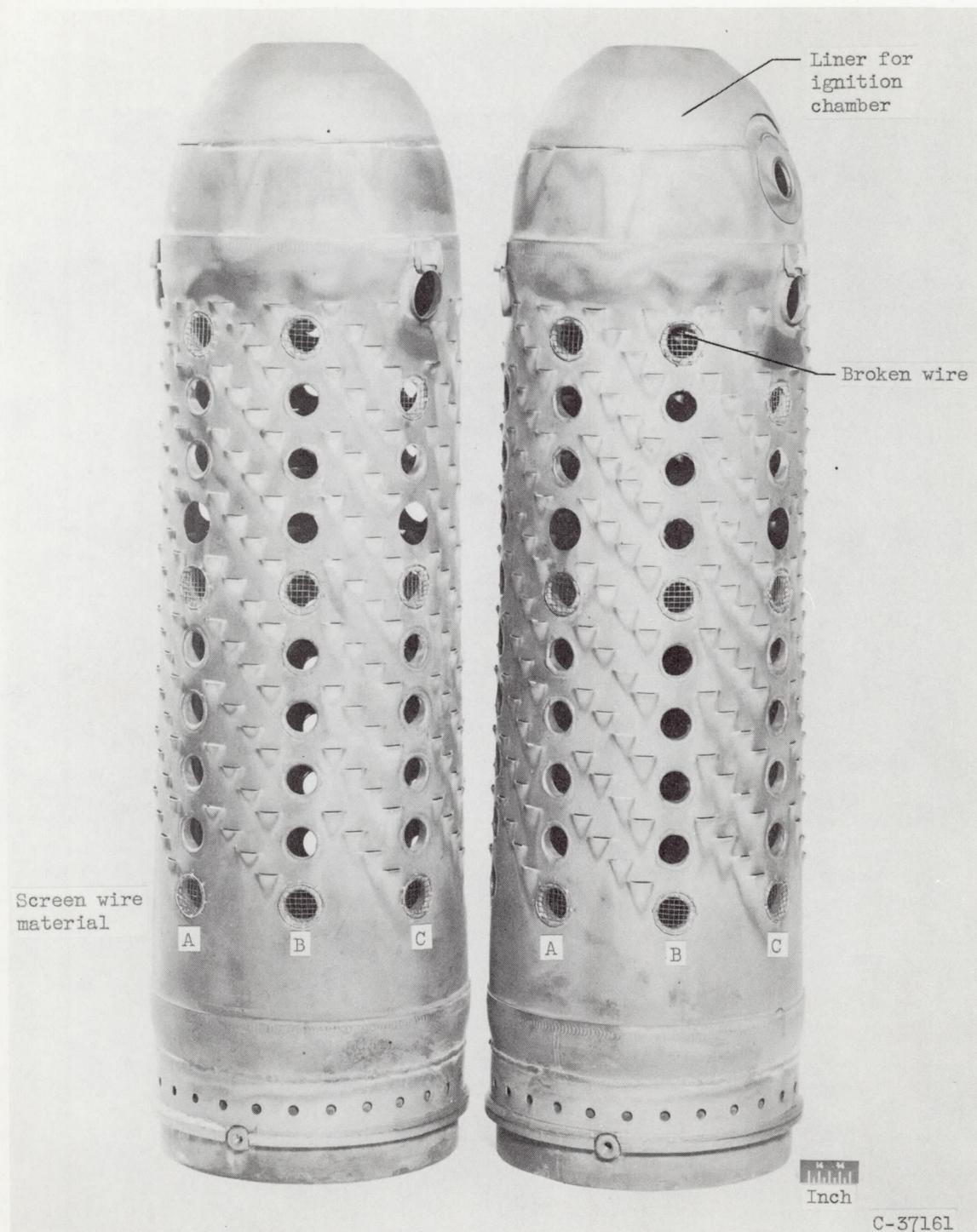


Figure 10. - J47 liners with 8-mesh screens of three heat-resistant wire materials after 45 hours of static sea-level operation. (Screens at ends and middle of each liner.)